

The Technique and Value of Doppler Ultrasonography

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Certain disease processes and certain complications of pregnancy are at least in part mediated by microtubule abnormality. Thus for example, impaired trophoblast migration of the spiral arteries is a major component in preeclampsia¹.

As a result there has been considerable interest in the application of Doppler techniques to the detection of complications of pregnancy, detection and characterization of certain fetal abnormalities, as well as an assessment of the value of Doppler in the detection and management of maternal disease².

The circulatory changes that occur during pregnancy involve modification of vascular structures within the uterus (e.g. spiral arteries), the development of microcirculation (the placenta and the fetus) and redistribution of blood flow and alteration of circulating blood volume³.

The female reproductive system contains some of the only adult tissues in which angiogenesis occurs as a normal process. This process results in rapid periodic growth and subsequent regression of tissue accompanied by rapid changes in Blood flow⁴. The changes in blood flow in both large and small vessels, pregnant and non pregnant cycles, can be monitored using color Doppler imaging⁵.

Doppler ultrasound analysis has been used in gynecology primarily to determine blood flow in ovarian tumors with neoplastic characteristics and in obstetrics to examine the relationship of blood flow in the uterine and umbilical artery to adverse fetal outcome^{1,6}.

The relationship of utero-ovarian blood flow to ovulation and implantation has been studied⁷.

This article will discuss the basis of Doppler ultrasound and the different physical & physiological factors which could potentially affect its use in investigating different conditions related to our everyday practice.

Doppler ultrasound is based on the Doppler principle, named after Christian Andreas Doppler (1842), which states sound and light waves change in frequency or wavelength when either the source or the receiver is moving⁸.

Doppler shifted echoes are generated when vessel walls on blood are in motion. These waveforms are familiar as sounds of Heart motion on fetal ultrasound and of pulsatile flow of blood through vessels⁸.

The frequency of sound waves is expressed in hertz, named after Heinrich Rudolf Hertz. One hertz (Hz) is one sound wave cycle or pulse occurring per second. Pulse repetition frequency is usually given in kilohertz (KHz), 1000 Hz/s are equal to 1 KHz and 1000 KHz/s equal to megahertz (MHz). Sound with frequency > 20,000 Hz is called ultrasound, because it is beyond the frequency range of human hearing⁵.

Instrumentation for Doppler measurement⁸

Utilizes separate voltage as generators and receivers to create a picture of the Doppler shifts in the area being examined similar to the grey scale, except that moving objects (e.g. blood flow) appear as red or blue against a black background.

Slow movement such as bowel peristalsis and vessel walls are scanned out by 'Wall' filters which reject selected ultrasound frequencies usually between 50 and 3200 Hz.

Color flow Doppler⁸

Provide two-dimensional, color coded Doppler information superimposed on the real time anatomical display. There is an upper limit to the Doppler shift that can be detected by pulsed instruments. If the Doppler shift frequency exceeds one half the pulse repetition frequency, a phenomenon called aliasing occurs, in which the peak of velocity waveforms appears below the base line.

Aliasing is the most common artifact encountered in Doppler ultrasound. Aliasing can be eliminated by increasing pulse repetition frequency, by increasing the Doppler angle, which decrease the Doppler shift for a given flow, or by baseline shifting. Flow velocity and flow volume can any be determined accurately if the angle of intonation is accurate measurement of the angle of insonation is usually done by the operator identifying a line on the anatomic display, so that it is parallel to the direction of Blood flow the resulting angle between the transducer and vessel may be included in mathematical calculation of velocity by the ultrasound computer program.

A 5° error by the operator in placing the directional line causes error in measurement of

velocity of < 2% when the real angle < 10°. This increases to 5.4% if the real angle is 30°, and to 12% when the angle is 60°. It is important, therefore to keep the angle of insonation as small as possible, consistent with determination of continuous waveform⁸.

The width of Doppler ultrasound volume box, compared to the width of the vessel wall, may also affect velocity estimation. In small vessels, the average velocity may be only one half the velocity at the centre of the stream, because of turbulence caused by friction from the vessel wall⁸.

Volume box widths which are too small in relation to vessel size and which are aimed at the centre of the stream may result in ventilation of velocity⁸.

The ascending uterine artery diameter width ranges from 0.2 to 0.5 cm the non-pregnant patients and becomes much larger in pregnant patients⁹.

Spiral arteries are closer to 1-2 mm in diameter volume box widths that are available usually start at 1 mm and increase to 10 mm in 1 mm increments⁹.

Pulsed Doppler Systems⁸

Have the ability to select the depth from which Doppler information is received, thus allowing analysis of Blood flow with in single vessel to do this. The vessel to be studied is just located with continuous wave ultrasound. Next a gate is placed over the vessel which passes only signals that are returned within a defined time.

Methods of analysis^{5,8}

1) Velocity Waveform analysis

Analyses the shape of the waveforms (e.g. presence or absence or reversal of the diastolic wave) may be of great clinical significance as in studying umbilical blood flow.

2) Resistance indices

(A) Resistance index (RI)

$$RI = (S - D) / S$$

Where the S is the peak systolic velocity and D is the minimum or end diastolic velocity. The RI is suitable for low resistance vascular beds with continuous flow throughout diastole. If the end diastole value (D) reaches zero, the ratio converges to 1.⁵

(B) Pulsatility index (PI)

$$\text{The PI} = (S-D) / \text{velocity}$$

Where S is the peak systolic velocity, D is the end diastolic velocity. Velocity is calculated from average of three or four cardiac cycles.

(C) Systolic/diastolic ratio (S/D)

The systolic/diastolic ratio is the simplest of all indices and is expressed by S/D, where S is the peak systolic frequency and D is the end diastolic frequency. It is less frequently used, now that (PI) and (RI) can be calculated by built-in software programs.

(3) Blood flow volume and velocity

(A) Flow Volume.

(B) Time averaged maximum velocity (TAMV)

It is frequently used when analyzing blood flow through small vessels with no collateral circulation, such as the umbilical and ovarian arteries, when diameter is not or can't be measured.

(C) Other measurement of velocity

Maximum peak velocity (MPSV) or simply peak systolic velocity (PSV) and minimum diastolic velocity (MDV).

Sources of Error in measurement^{5,8}

All blood flow measurements, whether they are of the uterus and ovary or the aorta and carotid arteries, are subject to many potential sources of error.

Certainly the most important source in the uterus and ovary are the operator's judgment in selecting the vessel to be examined and the particular part of the vessel on which to focus the Doppler.

Selection of the particular waveforms to analyze, out of the many available, is an equally important operator decision. It must be decided whether to select the ones with the highest peak systolic or diastolic velocity.

The angle of insonation is of greatest concern when measuring velocity and volume. Its importance is obviated for resistance indices which do not incorporate velocity in their calculation.

For angles < 20°, the maximum error in circulating velocity and volume caused by a 5% error in estimating the angle of insonation is <1.5% and is entirely obviated when angle adjustment is incorporated in the analytical software.

Identification of uterine and ovarian arteries^{9,10}

The complexity of utero-placental circulation makes accurate identification of the vessel under study difficult. With either continuous wave or duplex Doppler ultrasound flow velocity wave form are obtained from the lateral lower quadrants of the uterus angling the transducer toward the cervix. Signals achieved in this way are assumed to be originating from the uterine arteries.

The uterine arteries are more accurately identified using color Doppler. Identification of the ovarian arteries is possible at the supero-lateral angle of the ovary.

Identification of endometrial vessels⁷

This is possible within the halo area of the endometrium & subendometrium.

Table (1). Brief description of the role of Doppler in Obstetrics & Gynecology^{5,10}

	<i>Vessel and Doppler index used</i>	<i>Value</i>
<i>IUGR or fetal distress due to placental insufficiency</i>	1- Umbilical artery - RI - PI (if diastolic flow is decreased or absent) 2- MCA Doppler	- Diagnostic - Earlier sign of poor prognosis compared to BPP. - Its value was confirmed by several randomized controlled studies (unlike CTG) - When normal, can not predict the rate of deterioration of fetal condition because some case may occasionally progress very rapidly (e.g. preeclampsia & accidental hemorrhage). MCA flow (compared to umbilical flow) is a sign of brain sparing effect of blood redistribution in IUGR.
<i>Maternal diabetes mellitus</i>	Umbilical artery (RI, PI)	Poor value since most cases of fetal damage are not related to umbilical blood flow
<i>Fetal anemia (e.g. Rh isoimmunization).</i>	- Middle cerebral artery (MCA) - Umbilical vein	* Signs of hyperdynamic circulation are related to the degree of severity of anemia and may be used as a method of selecting patients for amniocentesis to reduce the latter's risks & frequency.
<i>Gestational trophoblastic diseases</i>	Uterine and spiral arteries	- suggest the diagnosis - Differentiate benign from malignant conditions - Suggest remission or recurrence - Investigate lesions suggestive of metastasis.
<i>Ectopic pregnancy</i>	Peri-trophoblastic flow (the circle of fire sign)	- help early diagnosis
<i>Endometrial receptivity</i>	- uterine artery (waveform and PI) - Endometrial and subendometrial vessel (color signal distribution)	- of some value in cases of IVF to decide on embryo-transfer versus freezing till later cycles (under study so far)
<i>Ovarian reserve</i>	Ovarian stromal vessels (PSV)	- Controversial, may be most useful in cases of IVF.
<i>Genital tract malignancy</i>	Uterine, spiral and ovarian vessels (RI, PI, PSV, color signal distribution).	- So far, under investigation but may prove to be of value to investigate ovarian and uterine masses suspicious of malignancy.

Identification of the middle cerebral artery (MCA)⁵

The skull is scanned as if to perform biparietal diameter measurement. A color Doppler examination is then performed in a plane slightly closer to the base of the skull, where the middle cerebral artery will be identified as a vessel crossing toward the probe from the circle of Willis in the Sylvian fissure.

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